Blow Molded Riot Shield
By Mike Sterner and Zach Ishman

An opportunity has been identified to blow mold a very important product that keeps many policemen safe in dangerous situations. The riot shield is a key component in keeping policemen safe without escalating the situation with the use of guns. It is normally made by thermoforming or compression molding two separate pieces of polycarbonate, or other impact resistant materials, and attaching them together with screws or bolts. Once this has been done, a nylon or polyester strap is usually attached to form a handhold for the riot shield. Below are examples of current products available (1, 2).

Figure 1: Current Riot Shield

Abstract
It is believed that by blow molding this product it may be able to be produced with less secondary operations and potentially improve the current design. When the two pieces of polycarbonate are attached to provide increased protection in the center of the shield it creates stress concentrations where the two layers are connected. Polycarbonate is especially susceptible to stress concentrations which can cause a weak spot in the part. By blow molding this, the entire part can be made at the same time, minimizing stress concentrations. By blow molding this part, it can also allow for more space between the front part of the shield that takes all of the impact and the back part that is usually in contact with the person it is protecting, this space in between the layers can help absorb more of the impact and reduce the amount of energy that gets through the shield and into the shield bearer. We believe that by modifying the design of current riot shields and by extrusion blow molding them, that a safer, more effective riot shield can be manufactured (1, 2).
Preliminary Design

The overall design is based on the major dimensions of most riot shields that are meant for this level of protection. All edges are rounded to allow the parison to fully fill out the cavity and remove sharp angles. One of the main design points is ambidexterity. The X-shaped divots provide a place for the user’s arm to rest in and increase stability when using the shield. Of course, handles and straps for the user’s forearm will be added post-process using the for mounting holes in the hand guard area. The handle and strap layout, paired with the arm divots, will allow for either arm to be used to hold the shield. The four outer corners of the front panel were also chamfered to prevent thin spots in the wall thickness, but also as an aesthetic feature to give it a more tactical and protective look.

Figure 2: Shield Design (Back)    Figure 3: Shield Design (Front)

The edges of the hand guard area were flared out at an extreme angle in efforts to maintain a more optimal blow ratio, as well as widen the support area it provides to the front panel and reduce hard angles.

Rather than being added post molding, the threaded mounting points for the handles and straps can be molded in. So long as the threads have a through hole like feature, this presents the possibility of using these points for blow pins and keeping them hidden. A more detailed representation of this idea can be found within the preliminary hand sketches section in Figure 6.
The wall thickness of the part’s wall is approximately 3mm with a 7mm gap between each wall to aid in the blowing process. 0.25 inches, or 6.35mm is the minimum recommended spacing between walls for flat planes to prevent the parison from adhering to itself before blowing. It was decided to go slightly above this 6.35mm to keep an even 7mm while ensuring that the part will be able to be blown properly during production. The air gap is also desired to aid in impact dampening, by having this air gap impacts can be absorbed throughout the front layer of the shield with less force transferring to the back layer and into the shield-bearers arm. This 7mm gap is referring to the thinner area of the part on each end, away from where the part is held. This area has a larger air gap between each layer to ensure that the object impacting the shield will not be able to transfer as much energy to the shield-bearers arm. Ultimately this prevents the outer lay from deflecting enough to contact the inner layer. This could also help protect the shield-bearer from sharp objects which may pierce the outer layer of the shield.

Another big attribute of non-ballistic riot shields is the weight of the shield. Typical non-ballistic riot shields weigh in between 6-10 pounds. According to the mass analysis performed on Creo, the current part weight is approximately 8.7lbs. This design is on the heavy side because of its double wall feature to achieve increased impact performance. If necessary the weight could be slightly reduced by decreasing the wall thickness, however this will decrease the amount of force that the shield can take. On the other hand, if the application demands more protection for the user, the wall thickness could be increased, or the space between the two layers could be modified with a different mold. Depending on the application, the design can be modified to fit it appropriately.

**Design Evaluation**

Because this is such a thin and wide part it would be difficult to determine an accurate blow ratio with a typical cylindrical parison. However, using GE’s guidelines on rectangular shaped parts, which is very similar to this design, they recommended using a blow ratio of 1.0, which will be this design’s target goal. The hand calculations shown below indicate the target parison radius if it were a circle, ideally for this part the parison should be extruded as an oval. Because of the large with of the part the edges of this riot shield will have a blow ratio of 1.459 with a circular parison as can be seen in figure 4. This could, however, be decreased with an oblong or oval die and mandrel to create a wider parison where needed.
All radii in the riot shield are above the minimum recommended radius as stated in the GE design guideline. The closest to the minimum are on the outside edge of the part, which are currently 2mm.

The parting line, shown to the right, was chosen because of the natural draft of the design. By making the parting line on this surface, it will follow mostly flat edges, until it reached the curved top and bottom of the part. Because of where we selected for the parting line, everywhere on the part has more than adequate draft angle, which will make ejecting the part from the mold easier. As of this point in time there are no ribs, gussets, or tack-offs in the part due to the fact that it is ideal for the riot shield to flex instead of breaking. Ribs would help increase the rigidity of the part but also create small stress concentrations which PC is very susceptible to. The current concern is that these ribs may end up cracking if exposed to too much energy, instead the goal is to have the part flex and absorb and distribute the energy around the majority of the part.

**Preliminary Designs**

When trying to conceptualize how to blow mold a riot shield, existing designs were used as reference. As previously stated, riot shields are traditionally either extruded or thermoformed sheets that are then assembled via secondary operations. Below are some examples of hand sketches showing some brainstorming drawings of how the new design might be laid out. This concept is not ambidextrous but serves more as a starting point for the final concept.
In the lower portion of the image are two drawings representing the ideas for two types of front panels. The design could either utilize a completely hollow structure with a thin air gap between the two layers of the front panel (Figure 6) or have the front panels be joined together with the only air gap between the front most layer and the hand guard (Figure 6).

The bottom left is a sketch showing how the parison would overmold around the threaded inserts to hold the handle in place. As previously mentioned, blow pins could then possibly be inserted through the threads and hidden underneath. If this does not work, blow pins could instead be inserted above and below the hand guard area. This would allow for a controlled release of air whenever the shield is struck, enabling one some control over the impact dampening between the shield and the user.
The figure to the right in figure 7 illustrates a possible design for the handguard area that allows for ambidextrous use. The lower bar could be an optional attachment that would allow the shield to be held with two hands in situations that require greater stability and control. All features can easily be removed or replaced to meet the user’s individual needs.

Figure 7: Handle Layout
These calculations were all conducted with a safety factor of 5 to ensure the part would not fail or deflect enough to harm the user. The force was identified by a study done by the graduate program at Pennsylvania State University in which a maximum force of 36,982N was exerted during an impact of a baseball bat. The moment of inertia was calculated using an excel spreadsheet created to identify the moment of inertia of a semicircle (shape of our riot shield). Assumptions made in this calculation are that the impact is across the entire width of the riot shield, which could lower our max deflection results, however this is also why a higher factor of safety was chosen. Below is an example of the spreadsheet used to calculate the moment of inertia of the shield. The modulus of 2200 MPA was chosen on the lower side of some of the PC grades in consideration to ensure that no matter which specific grade was chosen that the shield would be able to withstand the full impact of a baseball bat without deflecting too much(3,4).
Figure 9: Inertia Calculations

Figure 10: Material Selection Matrix
Identified Materials

Initially there were several different choices for different material families, however upon further research it was identified that PC would be the best choice for this application due to its high impact properties and ability to be blow molded. Other attributes that PC had that were favorable were good optical properties, and self-extinguishing properties, in case of Molotov cocktails or other instances where fire may be exposed to the shield. Other material properties such as PE and PP did not have the optical properties that were required, these materials also had significantly lower mechanical properties which are necessary in the demanding applications this shield may be exposed to. PMMA was also another potential choice, however it was not chosen because it does not have as good impact properties of PC in the thin layer that will be used in this design. PC was the clear choice in this application for the price point that is necessary for the production of the part(5,6,7,8).

Makrolon WB1239

This material was originally identified due to its higher viscosity compared to other PC materials on the market, in addition to the fact that it is transparent, which is an important aspect in the material selection of riot shields. However, the downside of this material choice is that it is not impact modified, which is extremely important in this application. This material was not selected as the final choice due to the fact that it cannot be made transparent and is only available in opaque colors. This is also not designed as a blow molding grade so while it does have high viscosity, it made create processing issues during manufacturing. Material data sheet is listed in the references for specific material values.


**Sabic Lexan PK2870**

This specific grade of polycarbonate is extrusion blow molding grade as well as impact modified and available in any transparent color, which is a perfect match to this application. Lexan PK2870 is currently the top choice for this application due to its superior impact properties as well as the ability for this material to be transparent. Impact is the most important material attribute of the riot shield so the material grade selected must ensure that its impact properties are superior to other grades of resin in the same family. Material data sheet is listed in the references for specific material values.

### Testing Standards:

#### 4.3. British Standards Institution


The standard addresses two levels of protection. Level 1 is the lower level of protection and requires the shield to pass a blunt and pointed impact test after both storage at 20 degrees centigrade and after being subject to flammability pre-treatment. Level 2 is a higher level of protection in that it requires the same tests as Level 1 plus additional requirements. Level 2 requires impact tests when subject to exposure to various chemicals and an edge impact cut test to simulate a machete-type attack. This test involves the shield being placed vertically under a falling carriage fitted with a sharp blade striker. The penetration of the blade into the edge of the shield is measured.

#### 4.4. Canadian Standards Association (CSA)


This standard applies to personal protective apparel intended to provide protection to the torso, arms, and legs, including joints, of correctional officers and law enforcement personnel from blows with blunt objects (e.g., rocks, stones, glass bottles, pipes, baseball bats, wooden planks, etc.) during riots, inmate control situations, and in any other situation in which there is a threat of violent attack to the torso, arms, and legs.

The aim of this specification is to establish guidelines for the conduct of ballistic tests which are designed to measure the level of protection which is provided by armours or the materials which are intended to be used in armours. Test threats may be fragment simulating projectiles.

Final Mold Details/Drawings

Figure 12: Mold Isometric
Figure 13: Mold Overall

Figure 14: Mold Details A
Figure 15: Mold Details B

Figure 16: Part Details A
Figure 17: Part Details B

Figure 18: Part Details C
Manufacturing Details

Process Type:
This design requires a single layer extrusion blow molding process, since this is one material, one layer, and rather large. It is the simplest and most common variation of EBM processes. Due to the large size of the parison necessary to mold this part, this process will also likely require an intermittent production method as opposed to a continuous process. Depending on cooling/blow times, this process could also utilize a shuttle system to maximize productivity and reduce material residence time, which can be an issue when processing Polycarbonate because of its thermal sensitivity.

Due to the extreme abuse the product will undergo during use and how reliable it must be, it is likely that the use of regrind will not be implemented to reduce scrap costs. However, this decision would need to be based on a series of experiments testing the effect of regrind percentage and generation on molded material mechanical, chemical, and optical properties. As an alternative, scrap can be either ground in house and sold, or simply sold to another party to reduce lost revenue.
Polycarbonate is also hygroscopic, so it will need to be dried prior to being processed. A desiccant dryer can be set up in line with the extruder to automatically feed in material as it is needed and drying at a given rate based on extruder output. A dry that will match the throughput of the machine should be selected to ensure that the material is dried enough, but not over-dried as this may result in material degradation. To prevent the parison from adhering to itself, a small amount of pre-blow may be required. If too much pre-blow is added, the parison may stretch prematurely or even rupture upon clamping.

**Advantages and Disadvantages:**

This part has been identified as a candidate for extrusion blow molding because of the many advantages of using this process type of the current type where the part is one extruded piece of polycarbonate and then one thermoformed sheet attached via drilled holes and clips. One main advantage of producing this part with extrusion blow molding is the fact that the stress concentrations can be eliminated by over molding around the connectors for the handles. By blow molding it also allows for the front and back later of the riot shield to be continuous and eliminate the need for attaching the two layers and adding more stress concentrations to the part. This is especially important when processing with PC because it is very notch sensitive. By doing this it also eliminates the secondary operation of attaching the two layers: outside shield, and inside piece that rests against the shield-bearers arm. This could reduce the cost to make it by saving money on the labor time that it takes to attach the two layers, in addition to the time it takes to drill the holes for the layers as well as the holes for the handles to attach.

Extrusion blow molding does, however, have some disadvantages that need to be addressed. It is believed though, that the advantages outweigh the disadvantages that this process has. One large disadvantage is the possibility of streaks throughout the part due to degraded material that is caught on the die or mandrel. This degraded material can stick to either part and cause small streaks throughout the part. One of the main features of a riot shield over a ballistic shield is that it can be completely transparent, so it is important that the part has good clarity. Another disadvantage is that there will be variations in wall thickness that can cause inconsistencies in shrinkage with can then cause warpage in the part. This can also cause some visual distortion when looking through the part. Another disadvantage is that when extrusion blow molding it is not likely that the surface quality will be the same as injection molding. This is not a big factor in this part, however it is another downside of choosing extrusion blow molding. The last disadvantage that was identified was the potential for weld lines at the top and the bottom of the shield where there is a pinch off where the mold closes. This is not ideal because PC does not have good weld strength in comparison to other materials, so it is possible that the weld lines may break if directly impacted on the top or bottom of the riot shield.
Equipment:

It is recommended that an accumulator head be used when long and heavy parts must be produced. They are designed to reduce the risk of parison sag, which would be detrimental to the integrity of the part. This specific part has a weight of 3.884 kg without accounting for any flash. Accounting for flash on the top and bottom of the part, the shot weight can be anywhere between 25-40% more than the trimmed part weight which would put the shot weight between 4.855 kg and 5.4376 kg. This is enough weight to cause a considerable amount of parison sag and justify the need for an accumulator head. After speaking to a representative from Bekum America Corporation, it was decided that a spiral head design accumulator would be the best option for this process. Specifically, the AKZ 20 head that Bekum offers would be able to provide the correct parison diameter and correct output to match our current calculations. The head can extrude a parison diameter of 330mm, which would almost perfectly match our calculated diameter of 348.2mm. This head should work perfectly paired with some pre-blow, which is also recommended with a part that is as long and narrow as the riot shield (9,10,11).

The spiral head accumulator, which was recommended by the representative from Bekum, will also be utilized to prevent weld lines from forming. The spiral design allows for the plastic to flow without forming weld lines and create weak areas on the part. This is vital to the integrity of the part due to Polycarbonate’s poor weld line strength and notch sensitivity. Due to the large parison diameter needed, a diverging die and mandrel will also be utilized to reduce die swell as recommended.

The machine that will be utilized is the Bekum BA-62S accumulator machine, which was recommended due to its large size and ability to accommodate the large riot shield that will be produced. The machine specs are attached below to further show the ability of this machine to produce this size of part(12).

The machine can accommodate a mold that is 200mm larger than the current part, leaving room to have pinch off and a cheek on the top and bottom of the mold. The width dimensions can fit a mold with a width of 1000mm with is considerably larger than the part which has a width of 508mm. This will allow for a considerable cheek width on both sides of the mold, allowing for a large space on the platen if the mold needs to be larger. The daylight between the platens is 1600mm which will allow for the part which is 76.20mm. This will allow for more than the width of the mold in addition to the recommended 190.5mm, or 2.5 times the part depth to eject. This will ensure that the mold will not only fit inside the platens but it will also be able to eject the part properly.

The machine is also capable of installing a mold with a maximum weight of 3000kg, which is more than enough weight, especially if the mold is made from aluminum. If the entire mold was made from solid aluminum the estimated mold weight would be less than 800lbs.
Even if a steel mold was required the approximate mold weight would still only be approximately 2300lbs. The machine is also able to pair with the accumulator head without extensive modification. When pairing all of this equipment together, it is believed that this setup should be able to efficiently and effectively produce the blow molded riot shield part (13).

PolyFlow:

Polyflow TOP

Figure 20: Polyflow EBM Run (TOP).
Figure 21: Polyflow EBM Run (FRONT).
Figure 22: Polyflow EBM Run (BACK).
After creating a model of each side of the mold halves, they were put into Polyflow in order to simulate how the part would be blown. The issue in the figure above, is the parison is not able to blow out to the outermost areas of the mold. The part is thin enough and the material is viscous enough that it will not blow out to the sides of the part. In real life this part would be molded using pre-blow to insure the parison would make it to the outside of the part before the part would be blown out, but it is difficult to simulate this in Polyflow. By using pre-blow it will make sure that the plastic is close to the outside of the part before it is blown out to insure that the outside of the part will be blown out sufficiently.

The issue that was encountered was simulating the preblow in Polyflow without making the parison too big that it would “spill” outside the part. While this would work in creating a part, it would not be ideal to do because this would create weld lines at the outside of the part and not be consistent with what would happen in real life. This part is made out of polycarbonate, which is extremely notch sensitive, so by making weld lines around the entire edge of the part it would greatly reduce the impact force that the shield could take without failing. This is why it is imperative that the part is blown to the edge of the part and not create a weld line.
To fix the simulation and create a part that would be similar to how it would be made in real life, the parison diameter must be adjusted to simulate the preblow. The parison must be big enough that it comes close to the edge of the part so it can be blown out, but it cannot extend past the part and create a weld line. This can be done by gradually increasing the parison diameter until the part is acceptable. If the parison diameter is adjusted significantly, the parison thickness should also be evaluated to insure the same amount of plastic is being used to form the part.

**ANSYS Mechanical:**

**3mm Wall:**

**Force Loadings**

Figure 24: Force Loading on Front Face.

**Fixed Supports**

Figure 25: Fixed Support Constraint on Arm-Guard Area.
The initial design of the blow molded riot shield is with a 3mm wall to survive against all different types of impacts and forces. The design is intended to be able to absorb the impact of even the worst case scenarios, such as a direct impact with a baseball bat. There was a study done at Pennsylvania State University where the maximum force of a baseball bat was calculated at approximately 36,982 N. This was used in hand calculations to come up with the initial wall thickness. This force however, is shock loading, so using ANSYS to simulate this impact would
need to be a different type of simulation that a static loading. This will need to be evaluated in the future to acquire accurate results.

Because of the different types of impacts and forces that riot shields encounter, there must be different types of simulations run to insure that the design will not fail. The simulation shown is the original design under a 200 lbf. Loading. This 200 lbf. will simulate the full weight of a person on the surface of the shield. Riot shields are often used in shield walls to force protesters or aggravators back, during this the protestors can often come in contact against the shield, pushing back on the shield bearer. The worst case in this scenario is that the person's entire weight is on the shield, which is what is being simulated. 200 lbs. is slightly higher than the average weight of a human male (195.5 lbs.), so it was chosen to be on the safe side when running the simulation.

As it can be seen in figure 28, the maximum deflection was only 1.3 inches at the bottom of the shield, where the highest moment is. This is a relatively small deflection and would be an adequate amount of deflection in the given situation. The maximum stress that the part encounters is also relatively low in comparison to the materials yield strength. The maximum stress encountered in this situation is approximately 5000 psi, which is much lower than the 9000 psi yield stress of the material chosen. This shows that the original design is adequate for this type of loading, and will not exceed the materials yield stress.

2mm Wall:

![Total Deformation](image)

Figure 28: Total Deformation of 2mm Wall.
A simulation was also ran where the shield wall thickness was reduced to 2mm in an attempt to reduce material usage, as well as decrease the weight of the shield itself. The part design was kept the exact same other than the wall thickness. The results of this simulation can be seen in figures 28 and 29. This time, the deflection was almost twice as much, at 2.4 inches. Again, this amount of deflection is acceptable for this situation, and will not impact the performance of the shield, or endanger the shield-bearer.

The maximum stress however, has increased slightly over the yield stress of the material. The maximum stress with a 2mm wall is 10,200 psi, in comparison to the 9000 psi yield stress of the material. This also exceeds the tensile stress at break, which is approximately 9427 psi. This means that at this loading condition the area of the part at this stress is likely to fail. At this area it is likely that the inside part of the shield will buckle and cause the shield to lose its integrity. This would result in the part failing and the shield bearer’s safety being in jeopardy, which is not acceptable.
Extended Rounds:

Total Deformation

Figure 30: Total Deformation of Extended Rounds at 3mm wall.

Equivalent Stress

Figure 31: Equivalent Stress Plot of Extended Rounds at 3mm Wall.
Großblas-Anlage
Large-size Blow Moulder

BA 62 S

Die abgebildete Machine enthält Extras zum Mehrpreis.
Machine shown with optional equipment.

09.13

Höhe 5.000 mm (mit Akkukopf AKZ 11)
Länge 7.400 mm
Breite 4.300 mm

Height 5.000 mm (with accumulation-head AKZ 11)
Length 7.400 mm
Width 4.300 mm
**Blasautomat**  
*Blow Moulder*

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Die tatsächlichen Verbrauchswerte für Elektroenergie und Kühlung sind artikelabhängig. Der Luftbedarf ist ein Durchschnittswert, er kann sich je nach Produktionsprogramm, z. B. durch Spülluft, wesentlich erhöhen.

Real consumption data for electric energy and cooling depend on the production. Compressed air requirement gives average value, may be remarkably higher for special productions due to cooling air demand etc.


*) Please note: Applicable for conventional materials such as standard SABIC 85429. Throughput rates depend on the material type. Binding data will be given on receipt of your details about material and master batch specifications.

Änderungen vorbehalten.

Alterations reserved.
Potential Mold Costs:

**A Half (Cav)**

Total Mold Cost

\[
C_{Workpiece} := Volume_{Workpiece} \cdot \rho_{Insert} \cdot k_{Insert} = 7578.41
\]

\[
C_{Total} := (C_{Workpiece} + C_{Machining}) \cdot NOC \cdot f_{Discount} = 17458.01
\]

**B Half (Core)**

Total Mold Cost

\[
C_{Workpiece} := Volume_{Workpiece} \cdot \rho_{Insert} \cdot k_{Insert} = 7947.27
\]

\[
C_{Total} := (C_{Workpiece} + C_{Machining}) \cdot NOC \cdot f_{Discount} = 17633.42
\]
Geometry Input Page

Basic Part Geometry (Only needed if you are machining an Insert)

Must come from CREO model

$Wall\_Thickness_{Part} := 3 \text{ mm}$

$Volume_{Part} := 10730827 \text{ mm}^3$

$Surface\_Area_{Part} := 1092320 \text{ mm}^2$

$f_{Part\_Complexity} := 1$ ** Set to 0 if machining a mold insert or set to 1 if machining anything other than a mold insert

Final Machined Part Geometry

$NOC := 1$ Number of Cavities/Parts to be Machined

$Volume_{Final\_Milling} := 151263338 \text{ mm}^3$ Final shape

$Surface\_Area_{Milling} := 1545084 \text{ mm}^2$ Includes Parting Line

$Surface\_Area_{Finishing} := 528069 \text{ mm}^2$ Area to be polished

$Volume_{EDMing} := 0.0001 \text{ mm}^3$ Set to 0.0001 if there is no EDMing done to the item to be machined

$Surface\_Area_{EDMing} := 0.0001 \text{ mm}^2$

$Length_{Drilling} := 1250 \text{ mm}$ For ejector pins, cooling lines, ...

$Diameter_{Drilling} := 9.525 \text{ mm}$

$Surface\_Finish := \text{"SPI A-2"}$ Enter in desired surface finish (Kazmer Book)
Workpiece Geometry

\[ Volume_{Workpiece} = 185882066.65 \text{ mm}^3 \text{ Initial shape} \]

Mold & Insert Material - Al 6061 - Kazmer - Injection Mold Design Engineering

\[ \rho_{\text{Insert}} = 2700 \frac{\text{kg}}{\text{m}^3} \]

\[ k_{\text{Insert}} = 15.1 \frac{\text{kg}}{\text{hr}} \]

\[ R_{\text{Material Volume}} = 0.001 \frac{\text{m}^3}{\text{hr}} \]

\[ R_{\text{Material Area}} = 0.024 \frac{\text{m}^2}{\text{hr}} \]

\[ R_{\text{Machining Rate}} = 23.94 \frac{\text{hr}}{} \]

\[ R_{\text{Finishing Rate}} = 13.52 \frac{\text{hr}}{} \]
Machining Factors (Kazmer)

\[ f_{Machining\text{-}Efficiency} := 0.25 \]
\[ f_{Drilling\text{-}Efficiency} := 0.05 \]
\[ f_{Milling} := 1 \]
\[ f_{EDMing} := 2 \]
\[ f_{Turning} := 0.5 \]
\[ f_{Drilling} := 0.5 \]

Insert Discount Factor

\[ f_{Discount} := \begin{align*}
\text{if } NOC &= 1 & = 1.000 \\
\text{else if } NOC &= 2 & = 0.85 \\
\text{else if } NOC &= 4 & = 0.72 \\
\text{else if } NOC &= 8 & = 0.61 \\
\text{else} & = 0.52 \\
\end{align*} \]
\[ R_{\text{Finishing}} := \begin{align*} &\text{if } \text{Surface\_Finish} = \text{“Texture”} & = 0.0200 \frac{m^2}{hr} \\ &\quad 0.0002 \frac{m^2}{hr} \\ &\text{else if } \text{Surface\_Finish} = \text{“SPI A–1”} \\ &\quad 0.0005 \frac{m^2}{hr} \\ &\text{else if } \text{Surface\_Finish} = \text{“SPI A–3”} \\ &\quad 0.001 \frac{m^2}{hr} \\ &\text{else if } \text{Surface\_Finish} = \text{“SPI B–3”} \\ &\quad 0.0025 \frac{m^2}{hr} \\ &\text{else if } \text{Surface\_Finish} = \text{“SPI C–3”} \\ &\quad 0.005 \frac{m^2}{hr} \\ &\text{else if } \text{Surface\_Finish} = \text{“SPI D–2”} \\ &\quad 0.01 \frac{m^2}{hr} \\ &\text{else} \\ &\quad 0.02 \frac{m^2}{hr} \end{align*} \]
Machining Costs

\[ t_{\text{Milling \_ Area}} := \frac{\text{Surface\_ Area\_ Milling}}{R_{\text{Material \_ Area}}} = 64.4 \text{ hr} \]

\[ t_{\text{Milling \_ Volume}} := \frac{\text{Volume\_ Workpiece} - \text{Volume\_ Final\_ Milling}}{R_{\text{Material \_ Volume}}} = 34.6 \text{ hr} \]

\[ f_{\text{Part\_ Complexity}} := \begin{cases} 0 & \text{if } f_{\text{Part\_ Complexity}} = 0 \\ \frac{\text{Surface\_ Area\_ Part} \cdot \text{Wall\_ Thickness\_ Part}}{\text{Volume\_ Part}} & \text{else if } f_{\text{Part\_ Complexity}} = 1 \\ 1 & \text{else} \\ -1000000 & \end{cases} = 1.000 \]

\[ t_{\text{Milling}} := \frac{t_{\text{Milling \_ Volume}} + t_{\text{Milling \_ Area}}}{f_{\text{Machining\_ Efficiency}}} \cdot f_{\text{Part\_ Complexity}} \cdot f_{\text{Milling}} = 395.99 \text{ hr} \]

\[ t_{\text{Area\_ EDMing}} := \frac{\text{Surface\_ Area\_ EDMing}}{R_{\text{Material\_ Area}}} \cdot f_{\text{EDMing}} = (8.333 \cdot 10^{-5}) \text{ hr} \]

\[ t_{\text{Volume\_ EDMing}} := \frac{\text{Volume\_ EDMing}}{R_{\text{Material\_ Volume}}} \cdot f_{\text{EDMing}} = 0.000 \text{ hr} \]

\[ t_{\text{EDMing}} := \frac{t_{\text{Volume\_ EDMing}} + t_{\text{Area\_ EDMing}}}{f_{\text{Machining\_ Efficiency}}} \cdot f_{\text{Part\_ Complexity}} \cdot f_{\text{EDMing}} = 0.00 \text{ hr} \]

\[ t_{\text{Drilling}} := \frac{\left( \pi \cdot \left( \frac{\text{Diameter\_ Drilling}}{4} \right)^2 \cdot \text{Length\_ Drilling} \right)}{R_{\text{Material\_ Volume}}} \cdot f_{\text{Drilling\_ Efficiency}} = 1.8 \text{ hr} \]
\[ t_{\text{Finishing}} = \frac{\text{Surface Area}_{\text{Finishing}}}{R_{\text{Finishing}}} = 26.4 \text{ hr} \]

\[ C_{\text{Machining}} = (t_{\text{Milling}} + t_{\text{EDMing}} + t_{\text{Drilling}}) \cdot R_{\text{Machining Rate}} + t_{\text{Finishing}} \cdot R_{\text{Finishing Rate}} = 9879.60 \] □

**Total Mold Cost**

\[ C_{\text{Workpiece}} = V_{\text{Workpiece}} \cdot \rho_{\text{Insert}} \cdot k_{\text{Insert}} = 7578.41 \] □

\[ C_{\text{Total}} = (C_{\text{Workpiece}} + C_{\text{Machining}}) \cdot \text{NOC} \cdot f_{\text{Discount}} = 17458.01 \] □
Geometry Input Page

Basic Part Geometry (Only needed if you are machining an Insert)

Must come from CREO model

\[ \text{Wall Thickness}_{\text{Part}} := 3 \text{ mm} \]

\[ \text{Volume}_{\text{Part}} := 10730827 \text{ mm}^3 \]

\[ \text{Surface Area}_{\text{Part}} := 1092320 \text{ mm}^2 \]

\[ f_{\text{Part Complexity}} := 1 \quad \text{** Set to 0 if machining a mold insert}
\quad \text{or set to 1 if machining anything other}
\quad \text{than a mold insert} \]

Final Machined Part Geometry

\[ \text{NOC} := 1 \quad \text{Number of Cavities/Parts to be Machined} \]

\[ \text{Volume}_{\text{Final Milling}} := 147209114 \text{ mm}^3 \quad \text{Final shape} \]

\[ \text{Surface Area}_{\text{Milling}} := 1178525 \text{ mm}^2 \quad \text{Includes Parting Line} \]

\[ \text{Surface Area}_{\text{Finishing}} := 549572 \text{ mm}^2 \quad \text{Area to be polished} \]

\[ \text{Volume}_{\text{EDMing}} := 0.0001 \text{ mm}^3 \quad \text{Set to 0.0001 if there is no EDMing done to}
\quad \text{the item to be machined} \]

\[ \text{Surface Area}_{\text{EDMing}} := 0.0001 \text{ mm}^2 \]

\[ \text{Length}_{\text{Drilling}} := 1250 \text{ mm} \quad \text{For ejector pins, cooling lines, ...} \]

\[ \text{Diameter}_{\text{Drilling}} := 9.525 \text{ mm} \]

\[ \text{Surface Finish} := \text{“SPI A-2”} \quad \text{Enter in desired surface finish (Kazmer Book)} \]
Workpiece Geometry

\[ V_{\text{Workpiece}} := 194929273.5375 \text{ mm}^3 \quad \text{Initial shape} \]

Mold & Insert Material - Al 6061 - Kazmer - Injection Mold Design Engineering

\[ \rho_{\text{Insert}} := 2700 \frac{\text{kg}}{\text{m}^3} \]

\[ k_{\text{Insert}} := 15.1 \frac{\text{kg}}{\text{kg}} \]

\[ R_{\text{Material Volume}} := 0.001 \frac{\text{m}^3}{\text{hr}} \]

\[ R_{\text{Material Area}} := 0.024 \frac{\text{m}^2}{\text{hr}} \]

\[ R_{\text{Machining Rate}} := 23.94 \frac{\text{hr}}{\text{hr}} \]

\[ R_{\text{Finishing Rate}} := 13.52 \frac{\text{hr}}{\text{hr}} \]
Machining Factors (Kazmer)

\[ f_{Machining\ Efficiency} := 0.25 \]
\[ f_{Drilling\ Efficiency} := 0.05 \]
\[ f_{Milling} := 1 \]
\[ f_{EDMing} := 2 \]
\[ f_{Turning} := 0.5 \]
\[ f_{Drilling} := 0.5 \]

Insert Discount Factor

\[ f_{Discount} := \begin{cases} 
1 & \text{if } NOC = 1 \\
0.85 & \text{if } NOC = 2 \\
0.72 & \text{if } NOC = 4 \\
0.61 & \text{if } NOC = 8 \\
0.52 & \text{else}
\end{cases} = 1.000 \]
\[ R_{Finishing} = \begin{cases} 
0.0002 \, \frac{m^2}{hr} & \text{if } Surface\_Finish = \text{"Texture"} \\
0.0005 \, \frac{m^2}{hr} & \text{else if } Surface\_Finish = \text{"SPI A–1"} \\
0.001 \, \frac{m^2}{hr} & \text{else if } Surface\_Finish = \text{"SPI A–3"} \\
0.0025 \, \frac{m^2}{hr} & \text{else if } Surface\_Finish = \text{"SPI B–3"} \\
0.005 \, \frac{m^2}{hr} & \text{else if } Surface\_Finish = \text{"SPI C–3"} \\
0.01 \, \frac{m^2}{hr} & \text{else if } Surface\_Finish = \text{"SPI D–2"} \\
0.02 \, \frac{m^2}{hr} & \text{else}
\end{cases} = 0.0200 \, \frac{m^2}{hr} \]
Machining Costs

\( t_{\text{Milling Area}} := \frac{\text{Surface Area}_{\text{Milling}}}{R_{\text{Material Area}}} = 49.1 \text{ hr} \)

\( t_{\text{Milling Volume}} := \frac{\text{Volume}_{\text{Workpiece}} - \text{Volume}_{\text{Final Milling}}}{R_{\text{Material Volume}}} = 47.7 \text{ hr} \)

\( f_{\text{Part Complexity}} := \begin{cases} 0 & \text{if } f_{\text{Part Complexity}} = 0 \\ \frac{\text{Surface Area}_{\text{Part}} \cdot \text{Wall Thickness}_{\text{Part}}}{\text{Volume}_{\text{Part}}} & \text{else if } f_{\text{Part Complexity}} = 1 \\ 1 & \text{else} \\ -1000000 & \text{else} \end{cases} = 1.000 \)

\( t_{\text{Milling}} := \frac{t_{\text{Milling Volume}} + t_{\text{Milling Area}}}{f_{\text{Machining Efficiency}}} \cdot f_{\text{Part Complexity}} \cdot f_{\text{Milling}} = 387.30 \text{ hr} \)

\( t_{\text{Area EDMing}} := \frac{\text{Surface Area}_{\text{EDMing}}}{R_{\text{Material Area}}} \cdot f_{\text{EDMing}} = (8.333 \cdot 10^{-9}) \text{ hr} \)

\( t_{\text{Volume EDMing}} := \frac{\text{Volume}_{\text{EDMing}}}{R_{\text{Material Volume}}} \cdot f_{\text{EDMing}} = 0.000 \text{ hr} \)

\( t_{\text{EDMing}} := t_{\text{Volume EDMing}} + t_{\text{Area EDMing}} \cdot f_{\text{Machining Efficiency}} \cdot f_{\text{Part Complexity}} \cdot f_{\text{EDMing}} = 0.00 \text{ hr} \)

\[ t_{\text{Drilling}} := \left( \frac{\pi \cdot \text{Diameter}_{\text{Drilling}}^2 \cdot \text{Length}_{\text{Drilling}}}{4} \right) \frac{R_{\text{Material Volume}}}{f_{\text{Drilling Efficiency}}} = 1.8 \text{ hr} \]
\[ t_{\text{Finishing}} = \frac{\text{Surface Area}_{\text{Finishing}}}{R_{\text{Finishing}}} = 27.5 \text{ hr} \]

\[ C_{\text{Machining}} = (t_{\text{Milling}} + t_{\text{ EDMing}} + t_{\text{Drilling}}) \cdot R_{\text{Machining Rate}} + t_{\text{Finishing}} \cdot R_{\text{Finishing Rate}} = 9686.15 \]  

**Total Mold Cost**

\[ C_{\text{Workpiece}} = \text{Volume}_{\text{Workpiece}} \cdot \rho_{\text{Insert}} \cdot k_{\text{Insert}} = 7947.27 \]

\[ C_{\text{Total}} = (C_{\text{Workpiece}} + C_{\text{Machining}}) \cdot NOC \cdot f_{\text{Discount}} = 17633.42 \]
References:


